MEMS for wireless integration

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Agenda

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- What is MEMS
- MEMS for wireless integration
- MEMS for tuning, Steering and filtering of radio frequency signals
- MEMS RF switches for superior performance and lower power

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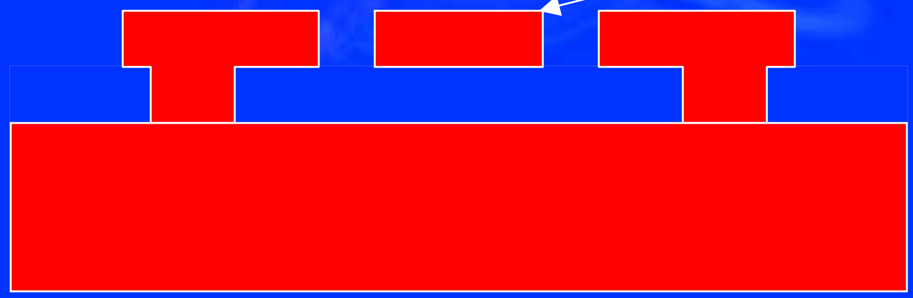
What is MEMS

- Micro Electro-Mechanical Systems
  - Micro: micro-fabrication technology & dimensions
  - Electro-Mechanical: electrical and mechanical components
  - Systems: integrating MEMS with “chips” e.g. I/O, controller
- MEMS is also referred to as Micro Systems Technology (MST) and Micro-Machines

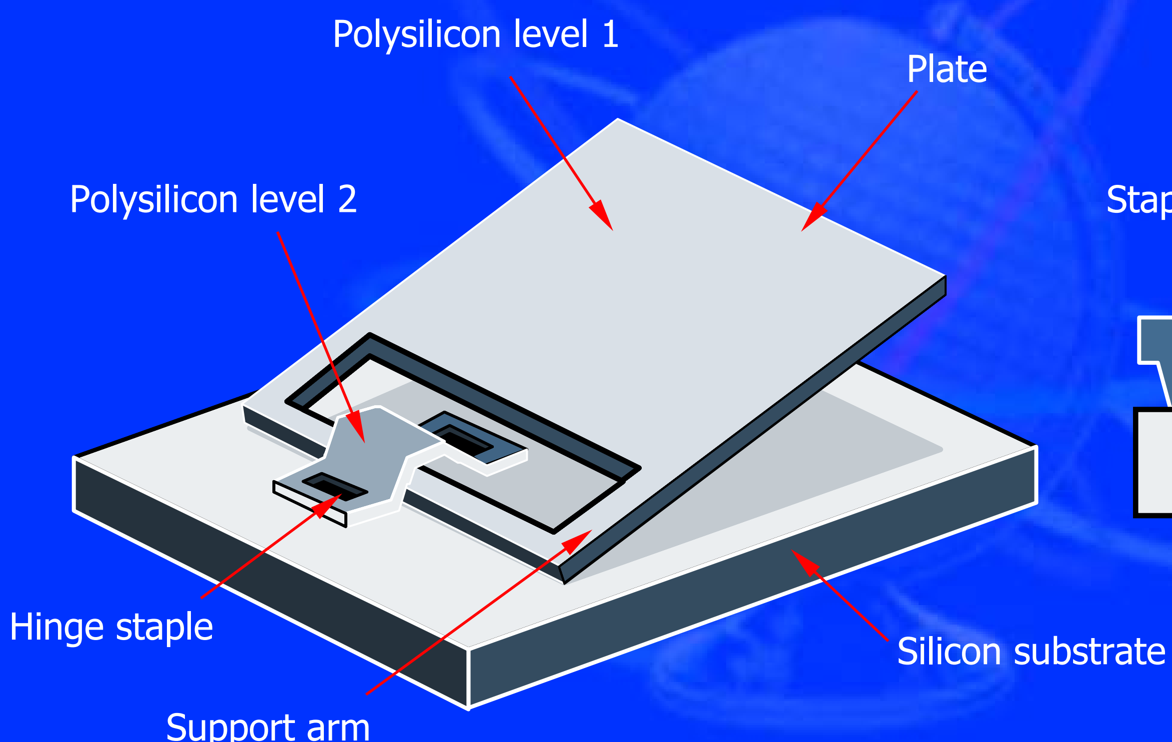
Surface Micromachining

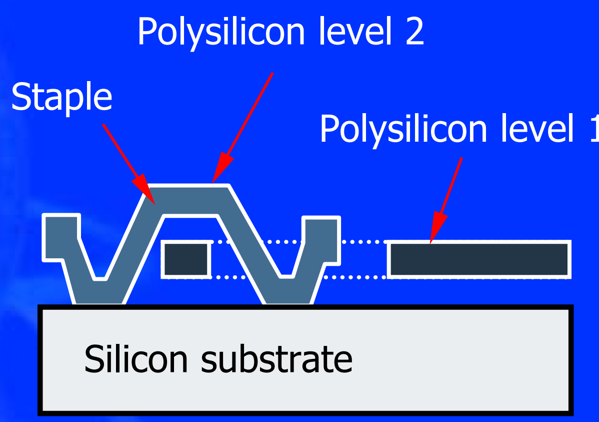
- Definition: MEMS that are made using films deposited on a wafer
  - The structural layer has the desired mechanical, electrical, and thermal properties, etc.
  - The sacrificial layer supports the structural layer until it is etched – the “release etch”



How MEMS are made

– A releasable hinge for a micro mirror

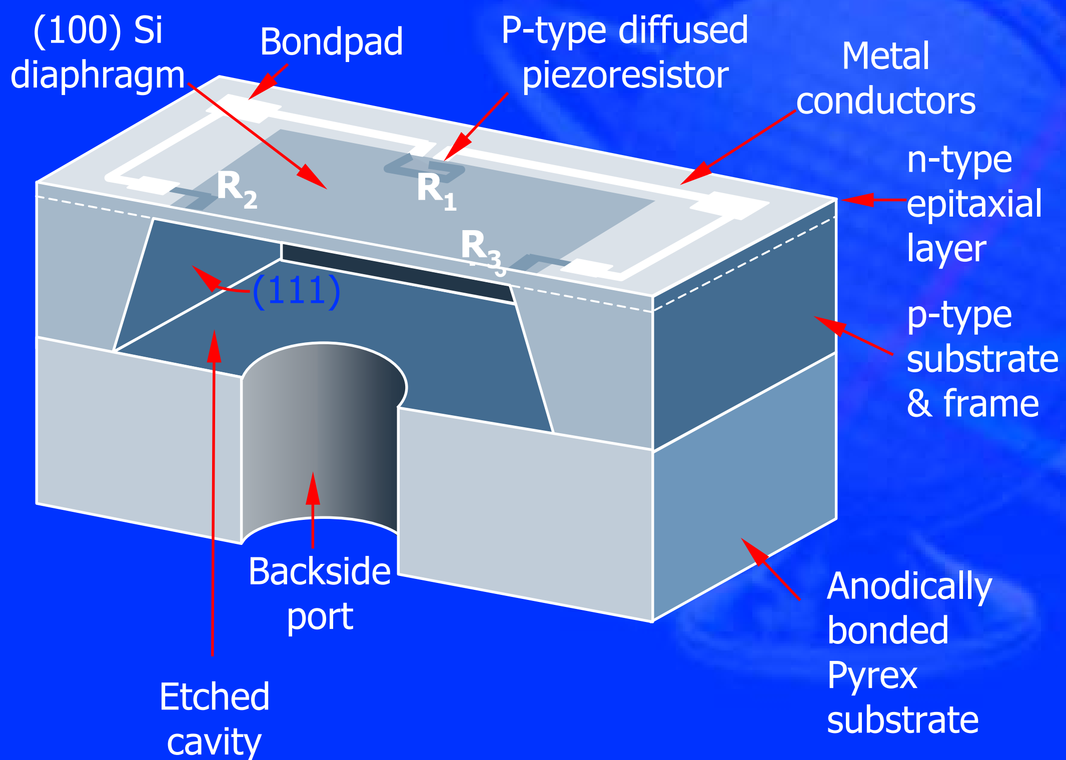


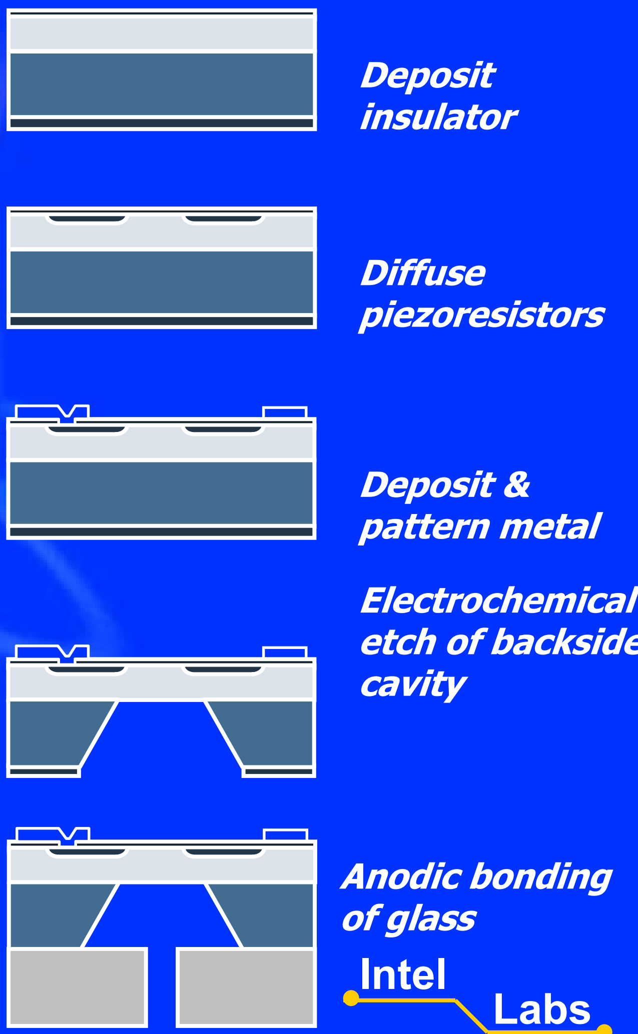


Picture Courtesy of Dr Bill Tang DARPA

How MEMS Are Made:

A Bulk Micromachined **Pressure Sensor**





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Picture Courtesy of Dr Bill Tang DARPA

MEMS is a technology
Not a product !

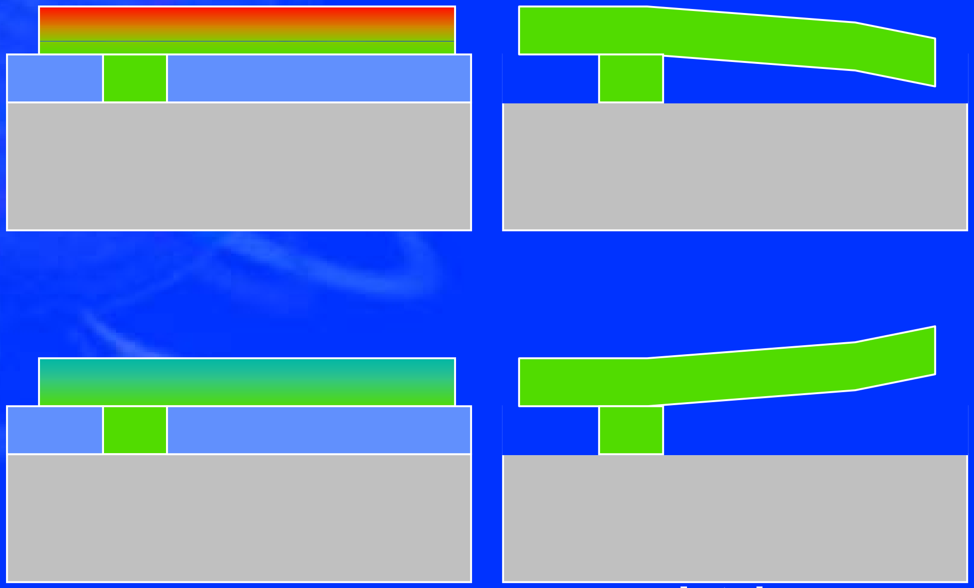
- **Just like CMOS it encompasses:**
  - **Design and simulation tools and methodology**
  - **Process technology**
  - **Packaging**
- MEMS MFG = CMOS + Micro-machining

- Litho	**Enables**
- Thin-film	**Moving**
- Etch	**Structures**
- Etc.	

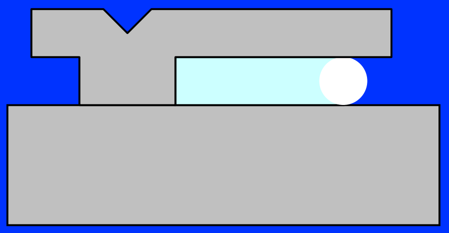
- ***Electrical* properties are important to silicon chips**
- ***Both electrical and micro-mechanical* properties are important to MEMS:**
  - **E.g Film stress leads to deformation of thin membrane**

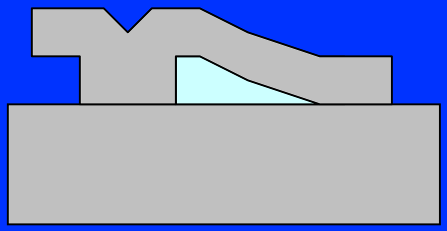
MEMS Processing challenges: Stress gradients

- A stress gradient is a difference in stress between the top and the bottom layers of a film.
- If the film is more compressive on top than on the bottom, the film curls down;
- If the film is more tensile on top than on the bottom, the film curls up.

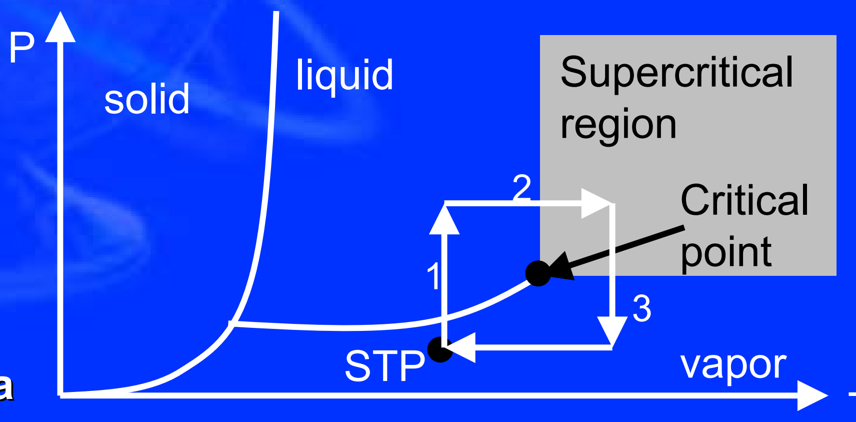


Releasing MEMS: The Stiction Problem





- **The problem:**
  - Surface forces (van der Waals, hydrogen bonding, etc.) are much stronger than bulk forces (spring restoring forces, gravity)
  - The meniscus that forms during drying pulls structures into contact
- **The result:**
  - MEMS stick upon contact
  - Common for MEMS that are mechanically compliant (e.g. varactor) or have small gaps (e.g. beam resonator)
- **Solutions:**
  - Avoid the meniscus by drying MEMS in supercritical CO_2, where liquid and gas phases are indistinguishable
  - Release etch with acid vapor or plasma



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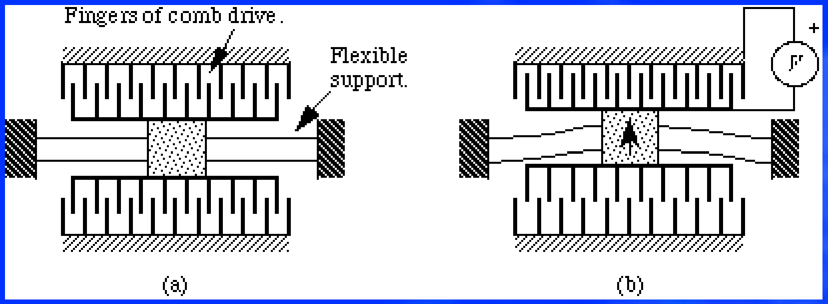
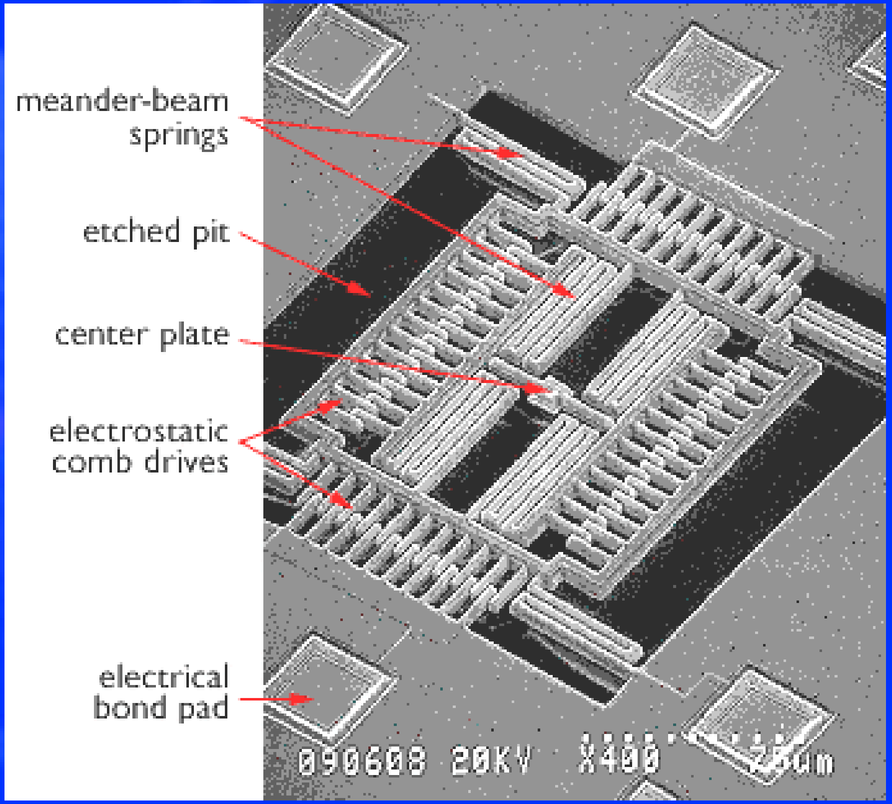
MEMS Actuation methods: Comb drive





- **COMB DRIVE**
- **Comb Drive (Left theory of operation, Right - a MEMS Comb drive (courtesy of Prof. Ken Gabriel CMU**

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Packaging Challenges

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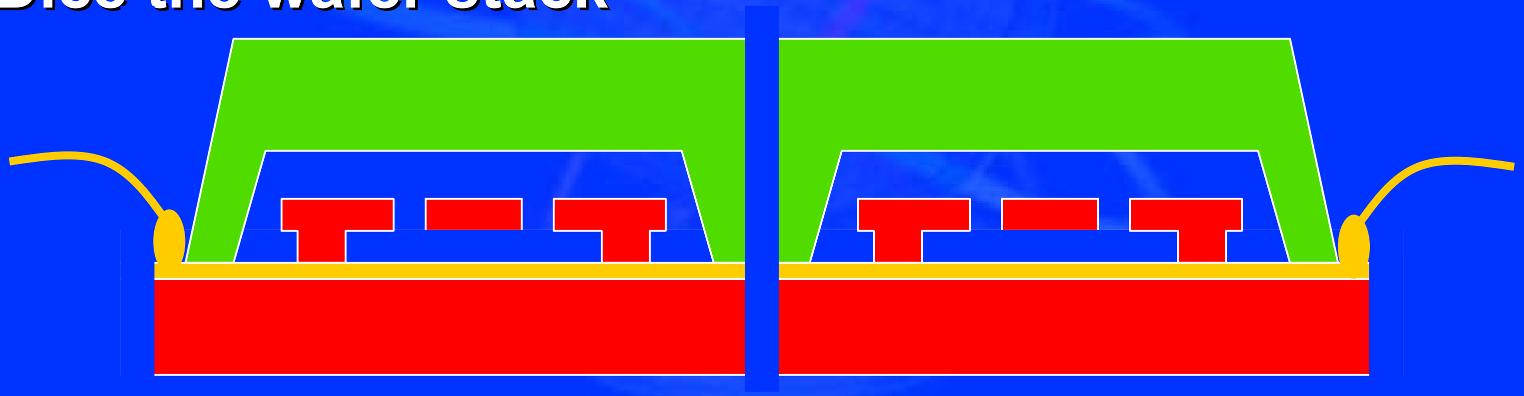
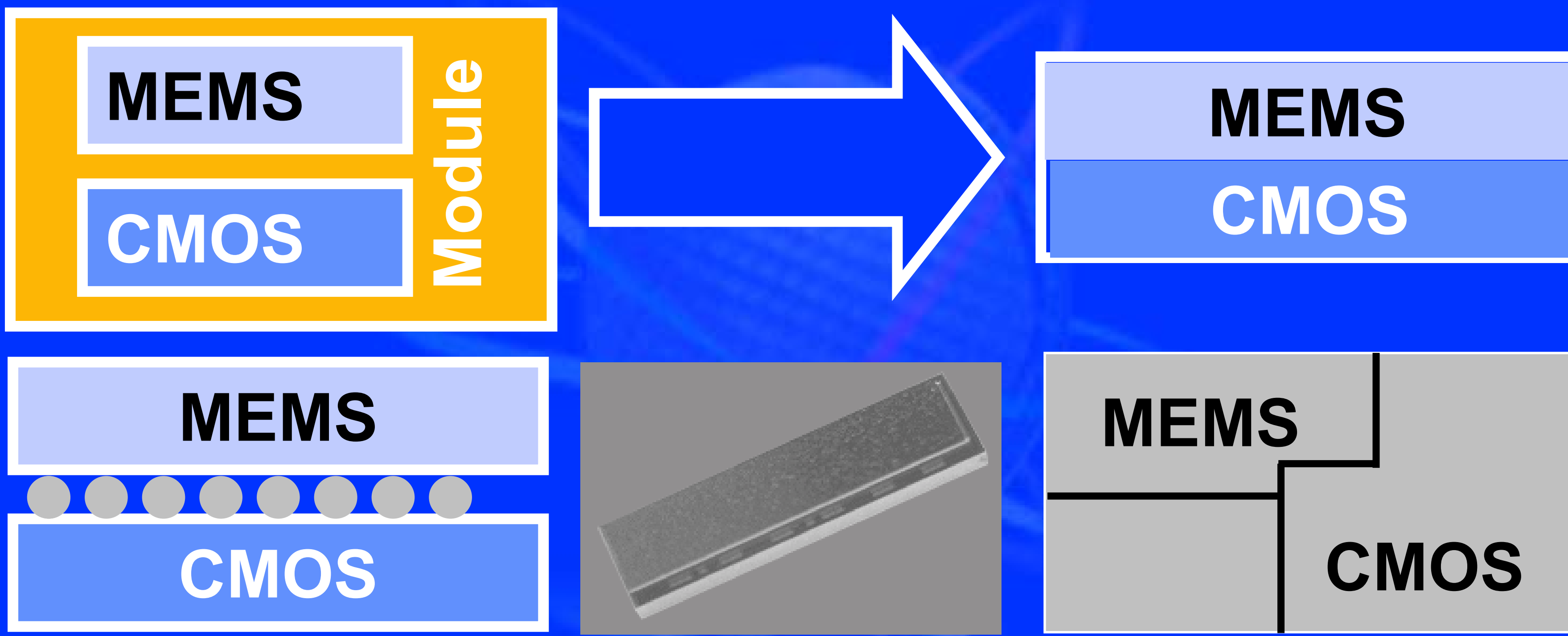
- A MEMS wafer cannot be diced with exposed devices
- A good solution is to
  - "Release" the MEMS wafer
  - Package by wafer bonding
  - Dice the wafer stack



- These packaging challenges are specific to MEMS

MEMS-CMOS integration

– Integration strategy is driven by cost



Hybrid Integration - Today

Monolithic Integration – Tomorrow ?

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The complexity of the MEMS market

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Pressure Sensor
Accelerometer
Print Heads
Micro Gyro

← Better Faster Cheaper

Displays
Biochips
Wireless
Optical Switch
Tunable Laser
VOA

← Brave New World of MEMS

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Intel Capital MEMS Investments

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OPTICAL TELECOM

Umachines

LIGHTCONNECT

WIRELESS

phone-or

DISPLAYS

Reflectivity

ir•i•digm

COVENTOR

CRONOS

COLIBRYS

INFRASTRUCTURE

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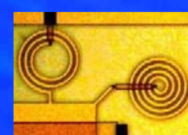
MEMS for wireless integration

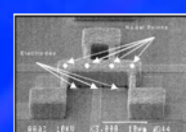
Antennas

Color bi-stable display

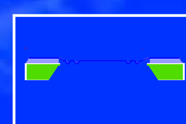
Micro-switches



Tunable capacitors and inductors



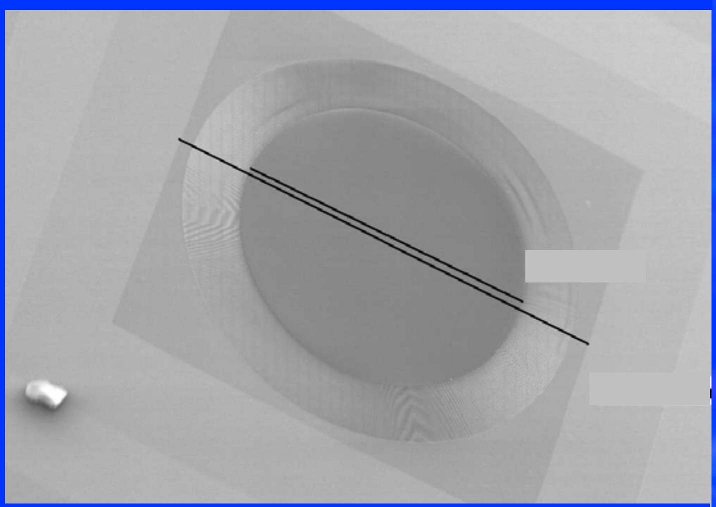
Tunable filters

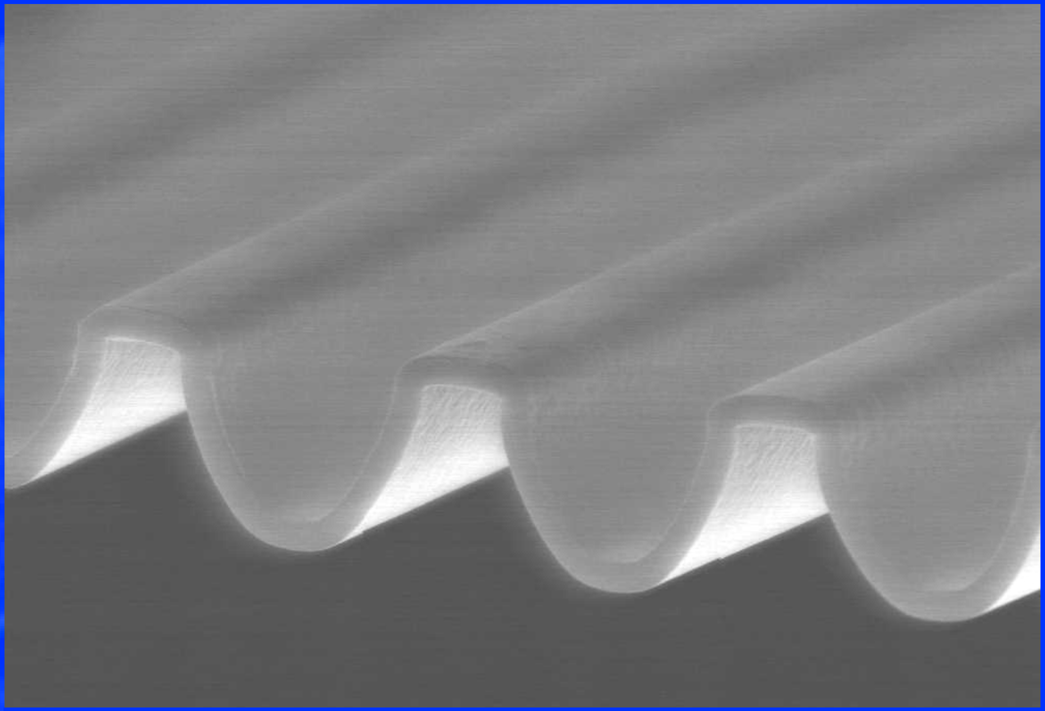


Directional microphone

MEMS Microphone - Corrugated Silicon Nitride Membrane

Top view





Microphone built in Intel FAB 8

MEMS for Wireless integration

- High Value passives
  - MEMS integration leads to lower size and cost of RF systems
- MEMS passive components provide lower loss and superior rejection of neighboring radio channels
  - Reduce amplification demands of RF electronics to improve battery life
  - Enable low cost frequency sources for future wireless devices

MEMS for RF delivers low cost, small footprint and extended battery life

MEMS for wireless integration

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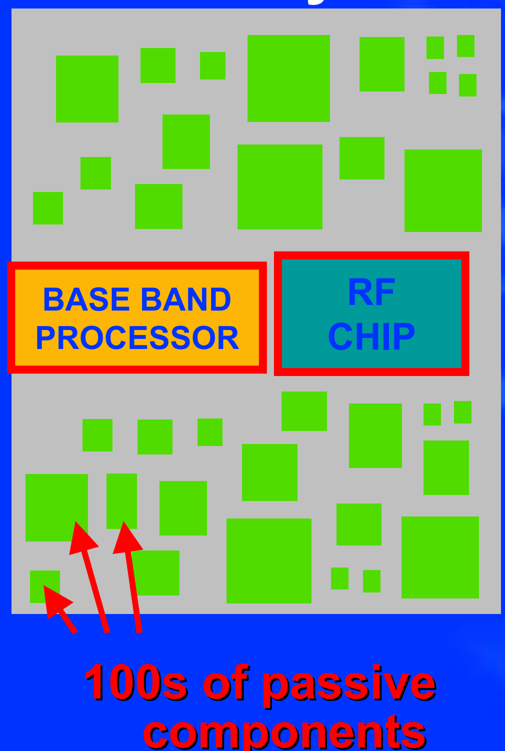
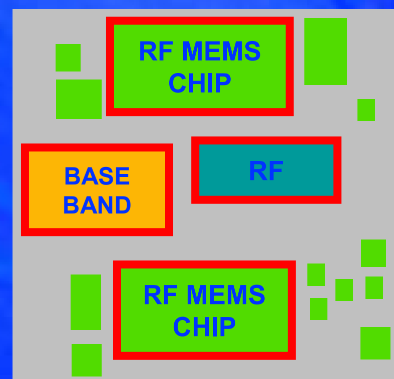
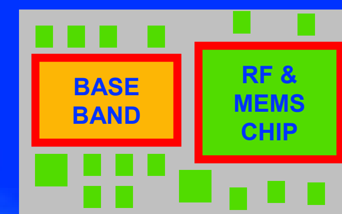
Today



Future (3 - 4 Yrs)



Future (4+ Yrs)



- **Silicon integration follows Moore's law**
- **MEMS research to enable:**
  - **"High Value" passives (Filters, Switches etc) to be built from Silicon and integrated together**

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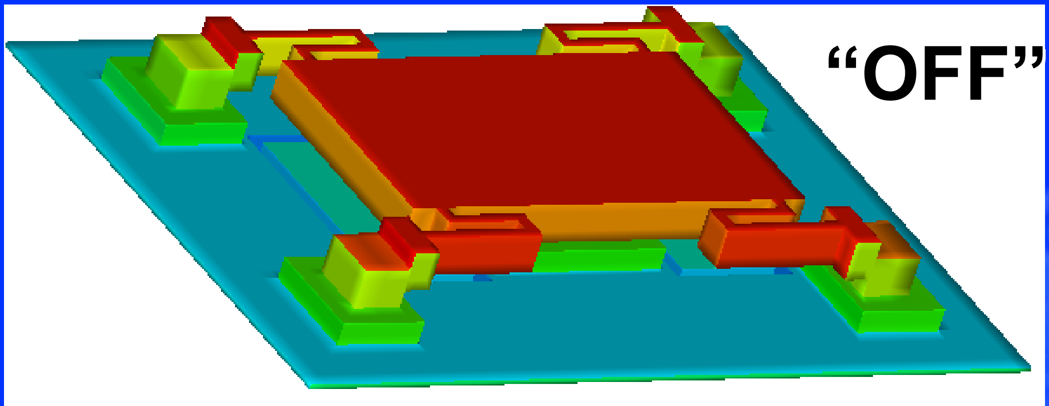
MEMS for tuning, Steering and filtering of radio frequency signals

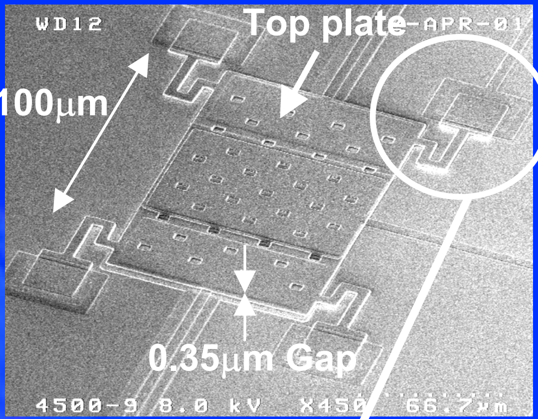
- Low loss, high linearity, widely tunable capacitors
  - Applications: High performance VCO
- Very low loss phase shifters enabled by MEMS switches:
  - Applications: Beam steering
- MEMS resonators
  - Applications: Integrated signal generation and processing

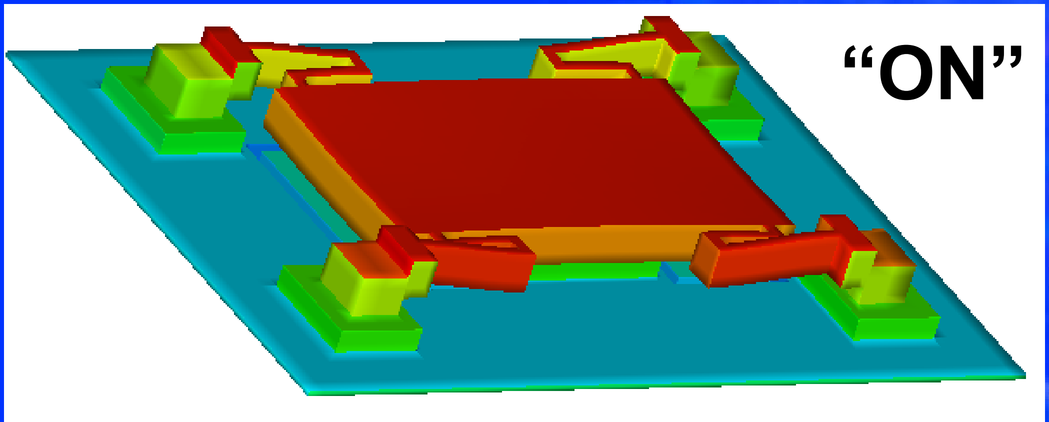
MEMS enables new architectural solutions for RF systems

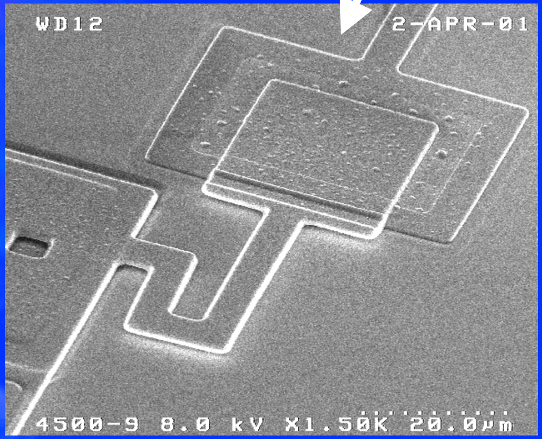
MEMS for tuning, steering and filtering of radio frequency signals

Surface micro-machined RF device









Top plate is like a 4 ft thick football field, suspended 1 ft above the ground !

A MEMS tunable capacitor and or switch

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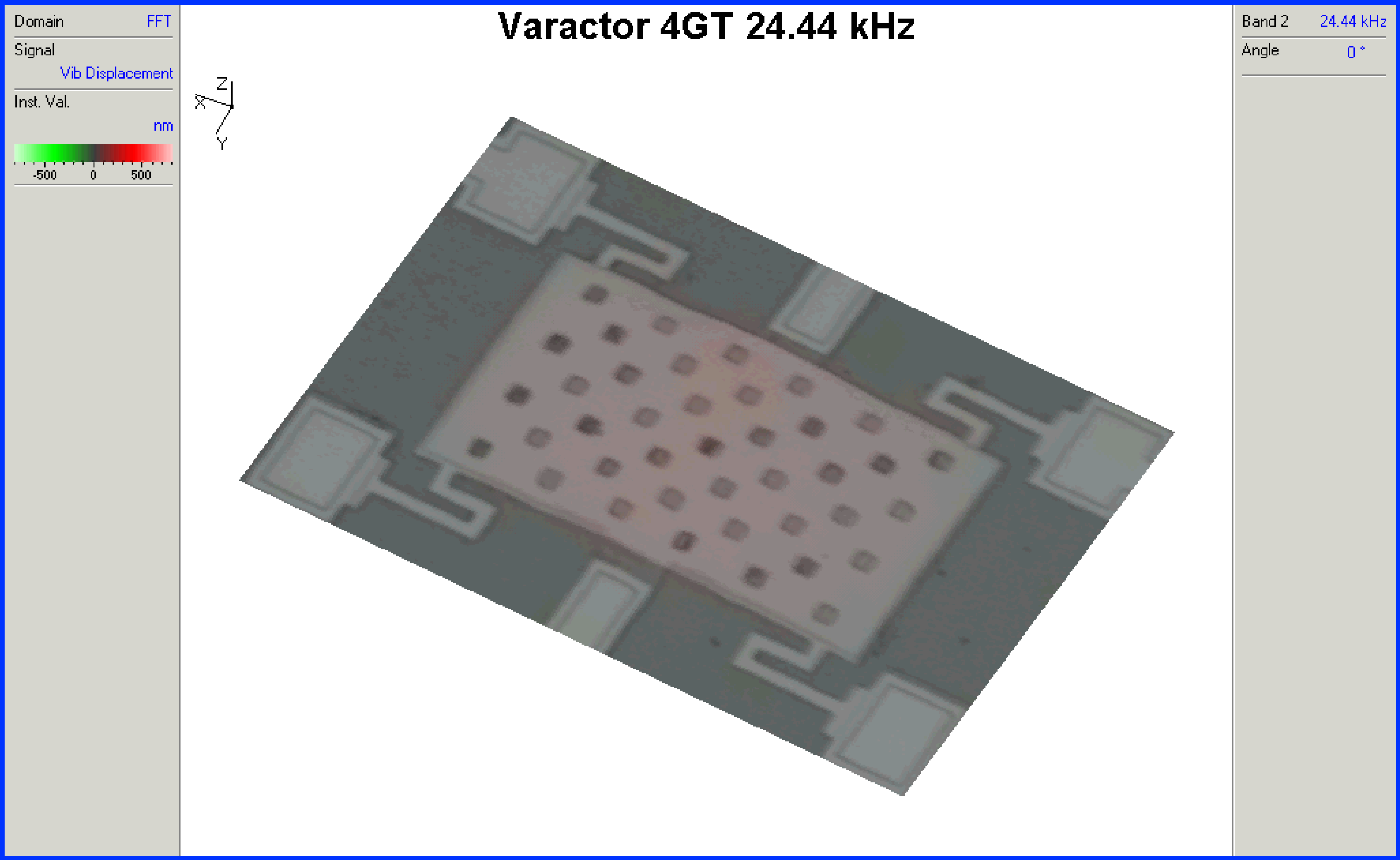
Varactor



Domain FFT
Signal
Vib Displacement
Inst. Val.
nm
-500 0 500
Varactor 4GT 24.44 kHz
Z
X
Y
Band 2 24.44 kHz
Angle 0 °

Varactor

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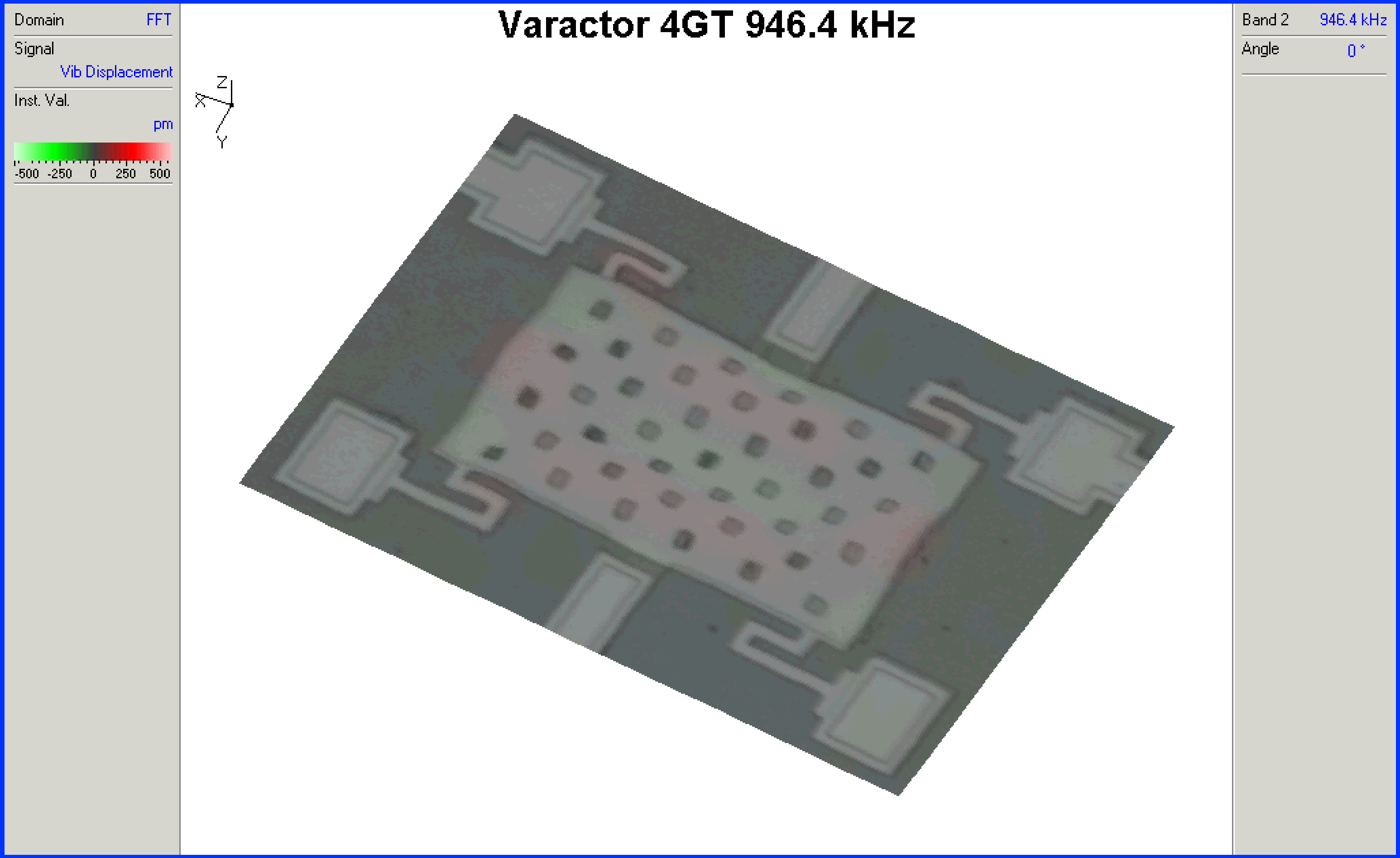

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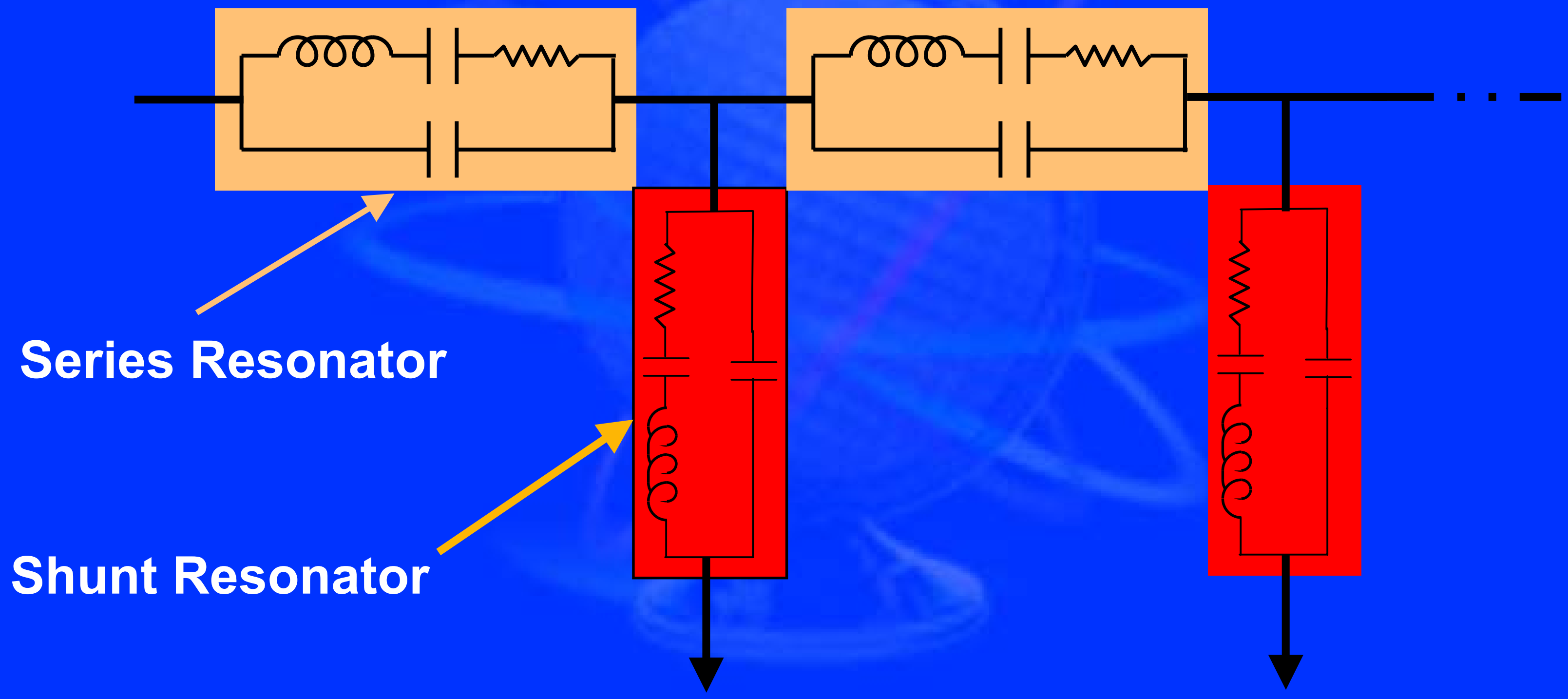
Filters building blocks



Resonator technologies

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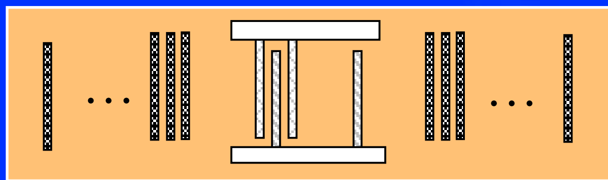
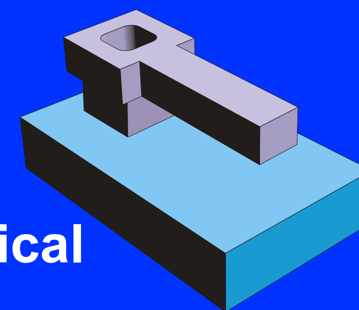
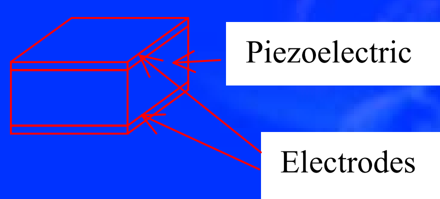


SAW (Acoustic)

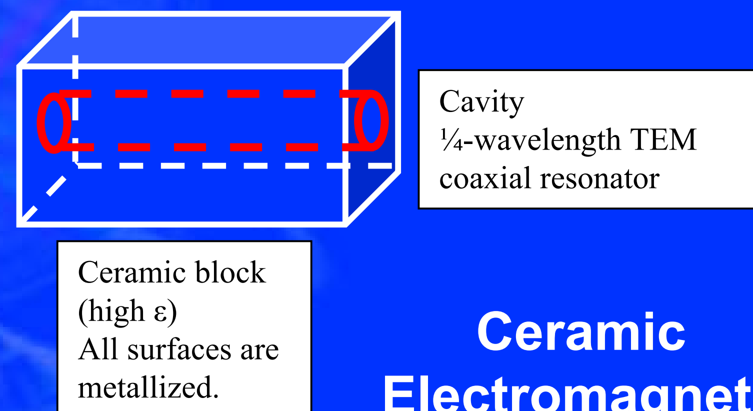


Electromechanical

Electromechanical



Thin Film Resonator (Acoustic)



Ceramic Electromagnetic

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Micro mechanical Resonator

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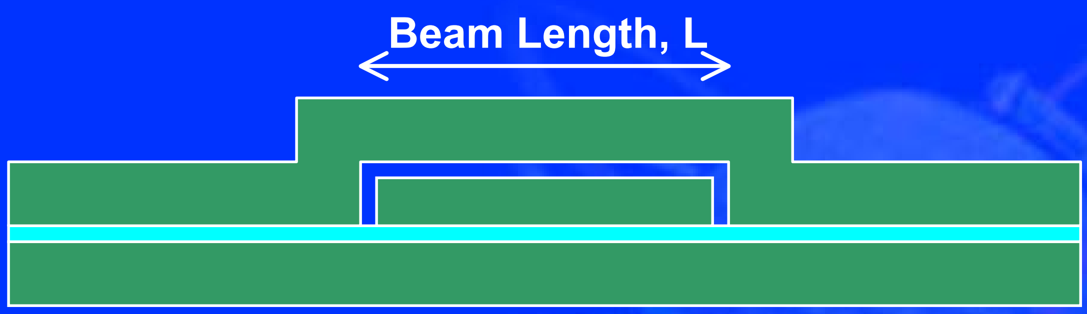

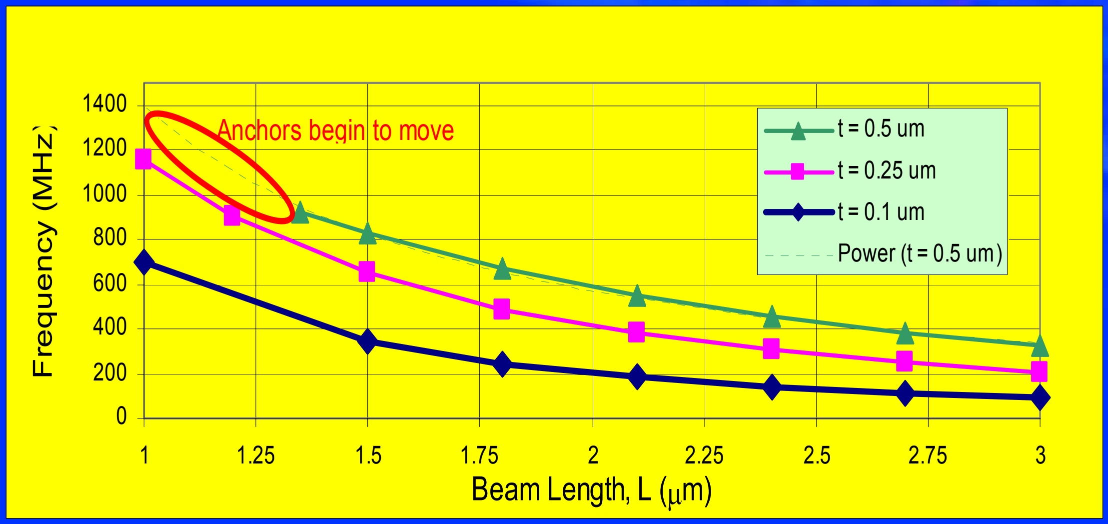

- High frequency micromechanical resonators with sub-μm dimensions have potential for on-chip oscillators
- Small gap is critical for electro-mechanical coupling,

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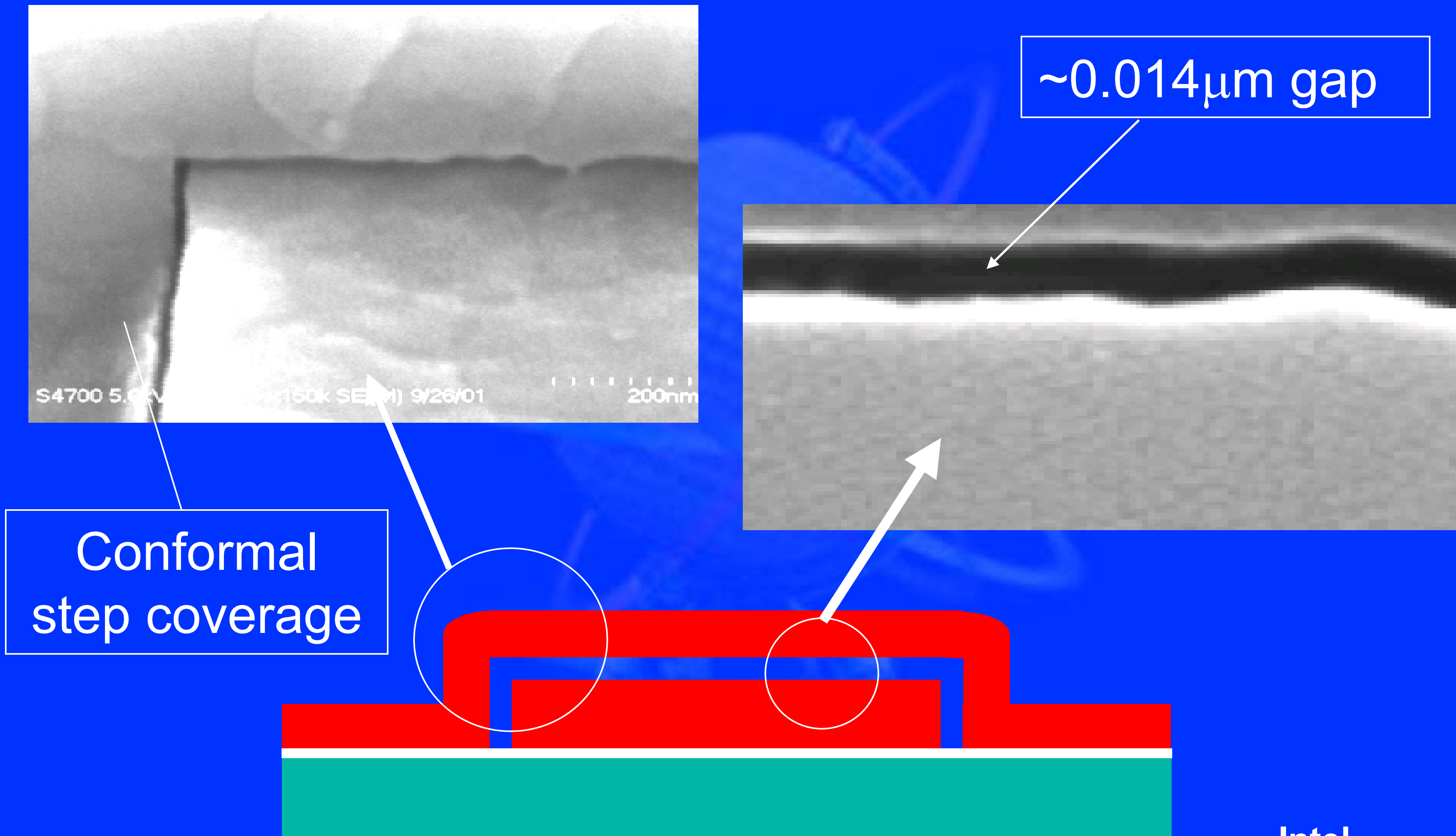
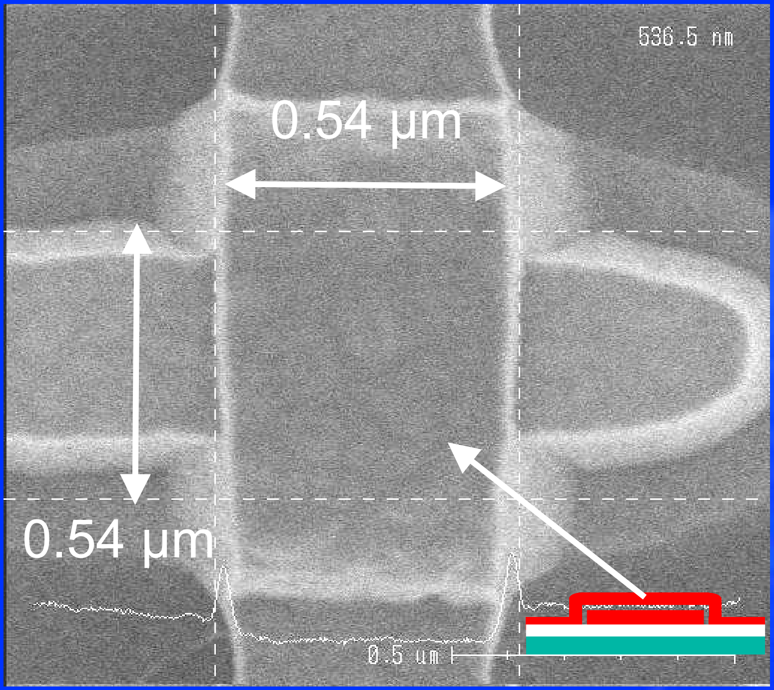
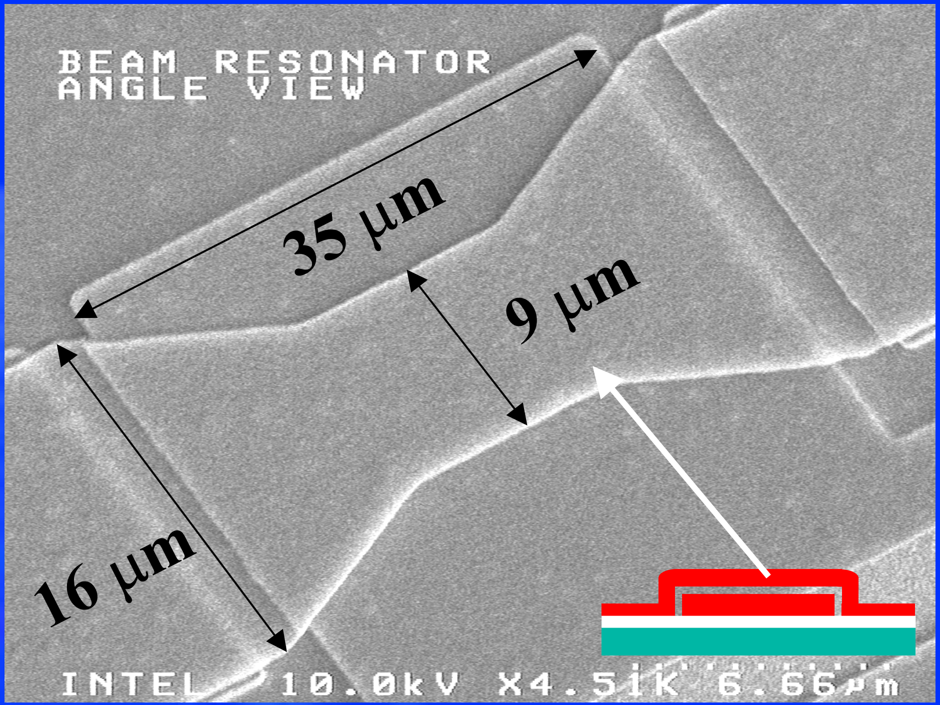
Beam Resonator with 0.014μm Gap



MEMS Resonators



Sub-micron
bridge resonator
2 GHz



Large bridge
resonator
3 MHz

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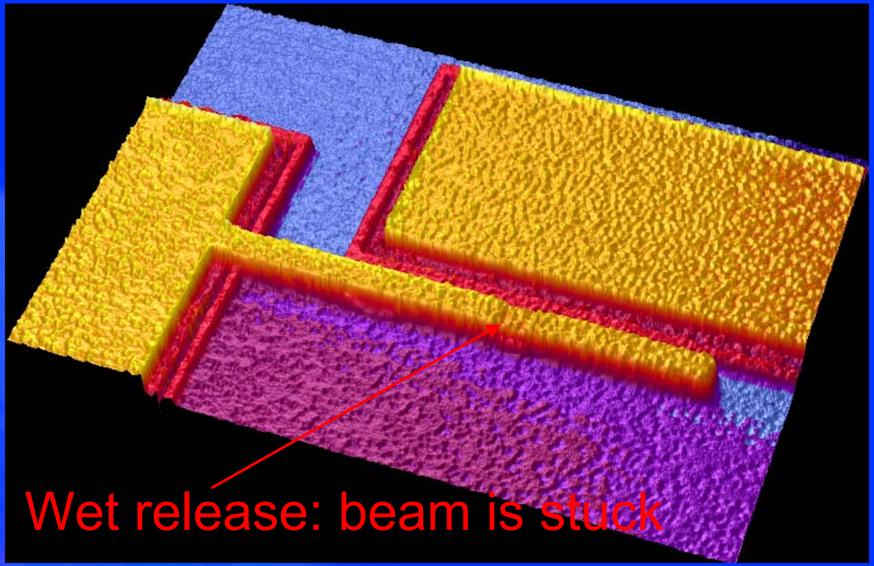
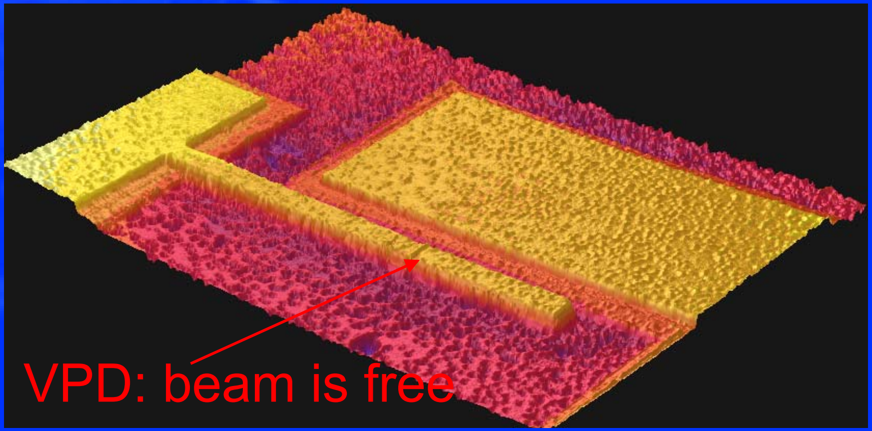
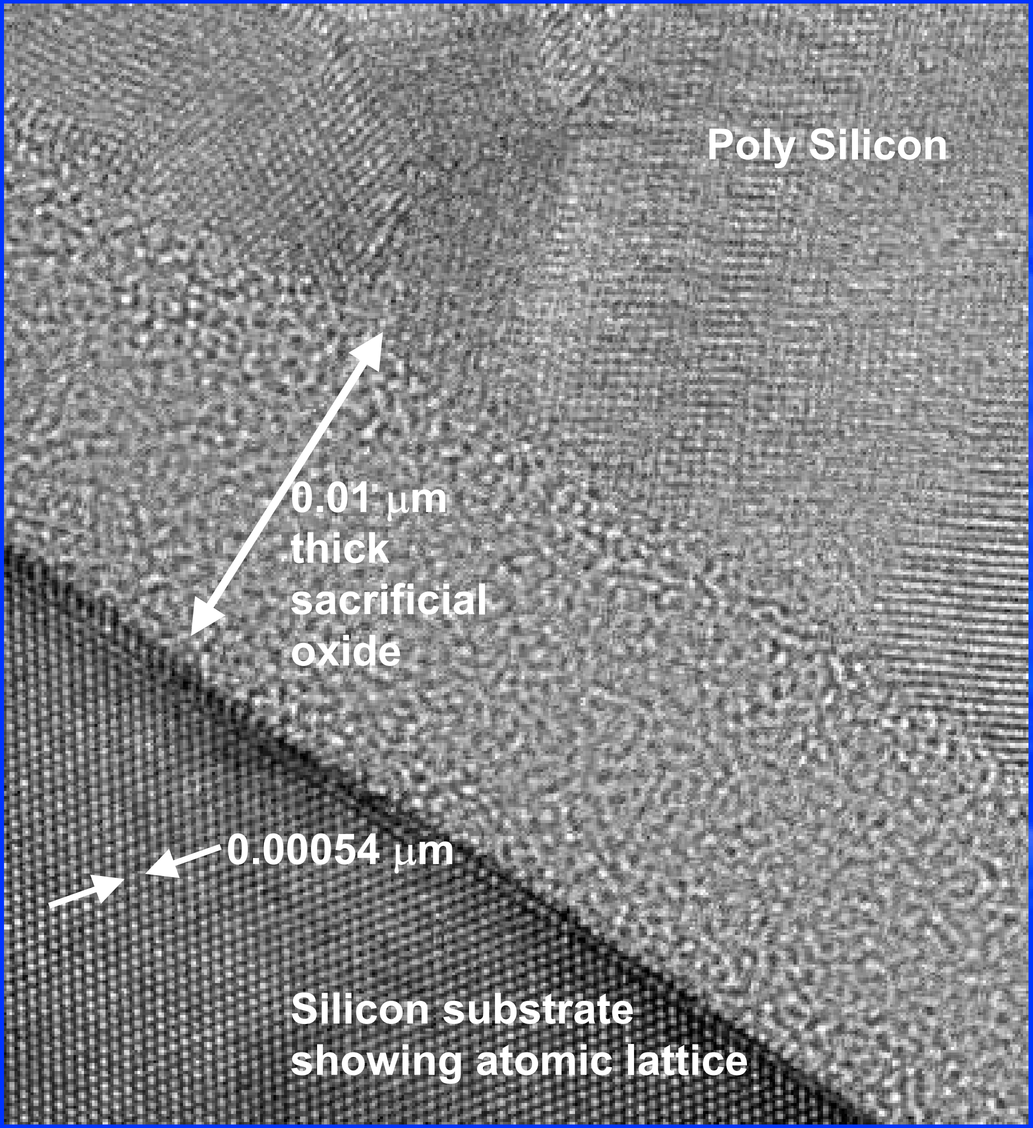
Beam Resonator Release

- Structure release very challenging due to small 0.03μm gap between poly0 and poly1
- Structure successfully released using HF vapor phase drying (VPD)
  - Avoids “stiction” of mechanical elements caused by exposure to liquid-vapor interface





Analytical Capability



- Intel's Advanced analytical capability enables visualization of nano scale MEMS structures
  - We can see what we have built !
  - Atomic resolution !

MEMS RF switches for superior performance and lower power

- Low insertion loss
  - Low signal attenuation provides increased battery life
- High linearity
  - Bi-directional with low signal distortion
- High isolation
  - Low cross channel interference
- Good switching speed (< 10 μs)
  - Suitable for cellular applications

MEMS switch gives substantial performance improvement for handsets

RF Switch

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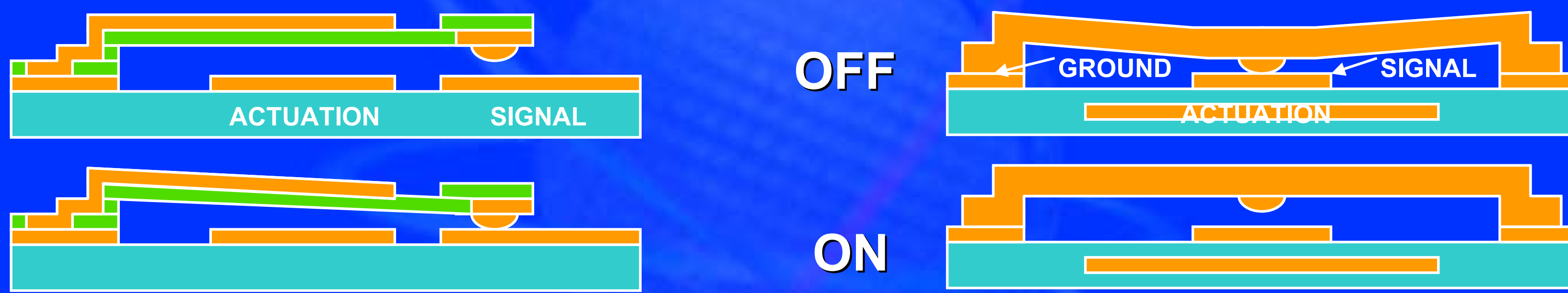
Series Shunt



- Insertion loss per switch ~ 0.1 db
- Isolation per switch ~ 50 dB or better up to 3GHz
- Switching speeds < 10 μs

MEMS Benefits to wireless

- Higher integration:
  - Complete wireless system can be reduced to 2 or 3 chips
  - 50% reduction in footprint due to higher integration
- Higher performance:
  - Battery life improvement by 30 % or greater due to lower insertion loss

Summary

- MEMS for RF delivers low cost, small footprint and extended battery life
- MEMS enables new architectural solutions for RF systems
- MEMS switch gives substantial improvements for handsets

Call to Action

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- Optimize RF architectures to exploit the full capabilities that MEMS components can provide
- Deploy high value MEMS passive components in wireless handsets in the 3-4 year time frame
- Evolve tight integration of MEMS, Analog and RF functions in the longer term

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Collateral

- Where attendees get additional and updated information from the Intel Web Site:
  - MEMS Micro-Mechanical Systems
    http://www.intel.com/research/silicon/mems.htm
  - Interview with Valluri Rao, Intel Fellow directing Intel's MEMS research and development activities
    http://www.intel.com/research/one_on_one_rao.htm
  - For a broader view of these technologies, visit the Silicon Showcase
    http://www.intel.com/research/silicon/

MEMS for wireless integration

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